International Journal on Electrical Engineering and Informatics - Volume 8, Number 1, March 2016

Bat Algorithm and Firefly Algorithm for Improving Dynamic Stability of Power Systems Using UPFC

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Abstract: In this paper a hybrid method for improving the dynamic stability of the power system using UPFC is proposed. The novelty of the proposed method is combined performance of the Bat-inspired algorithm and Firefly Algorithm (FA), which provides improved searching ability, automatic subdivision and random reduction. Here, the bat-inspired algorithm optimizes the maximum power loss bus while the generator fault occurs, which inturn affects the power flow constraints like voltage, power loss, real and reactive power. For improving the dynamic performance, the optimum capacity of UPFC has been determined with minimum cost by using the FA algorithm. The attained capacity UPFC has been located in the affected location and analyzes the power flow of the system. The proposed method is implemented in the MATLAB/simulink platform with IEEE 30 and IEEE 14 standard bench mark system. The proposed method performance is evaluated by comparison with different techniques like hybridized Gravitational Search Algorithm (GSA) and Bat algorithm. The comparison results proved the effectiveness of the proposed method and confirm its potential to solve the problem.

Keywords: Bat algorithm, FA, power loss, voltage, GSA, dynamic stability

1. Introduction

Electrical power techniques happen to be pressured to work in order to maximize or minimize the total capacities worldwide due to the the environmental along with economic constraints to emerge a new generating plants and transmission lines [2] [3]. The quantity of electrical power by safety along with steadiness restraints, that may be handed down among 2 opportunities by way of a transmission system is restricted [1]. Power flow in the lines and transformers shouldn't be allowed to raise into a level in which a haphazard occurrence might lead to the actual system fall down as cascaded breakdowns [4] [5]. The machine is actually assumed for being blocked any time such a limit reaches. Taking care of impediment to decrease the actual restrictions in the transmission system within the dynamic current market possesses, as a result, develop into the actual central movement of systems operators [6]. It has been analyzed the not enough management connected with transactions may improve the congestion cost which is a added as load on consumers [7].

With regard to managing the power transmission system, Flexible Alternating Current Transmission System (FACTS) is often a fixed device that's utilized [8] [9]. FACTS is regarded "an electric power automated dependent process along with other fixed device in which present management of a number of AC transmission system parameters to build up controllability in addition to magnify power transfer capability" [10]. The actual several types of FACTS devices available for this function contains Static Var Compensator (SVC), Thyristor controlled series Capacitor (TCSC), Static Synchronous series compensator (SSSC), Static Synchronous Compensator (STATCOM) [43-45], Unified Power Flow Controller (UPFC) and Interlink Power Flow Controller (IPFC) [12]. UPFC is probably the FACTS devices included in this, that will dispense the facility of power flow in transmission line which includes active and reactive voltage component in chain with the transmission line [11] [13]. Completely new prospects for controlling power and also improving the utilizable potential

Received: October 20th, 2015. Accepted: March 21st, 2016
DOI: 10.15676/ijeei.2016.8.1.12

regarding surviving transmission lines are usually released up through the look of FACTS tools [14]. The optimum position regarding UPFC device permits to manage its power channels for an interconnected system, and thus to raise the system load ability [15]. On the other hand, restricted variety of devices, away from which often that load ability can easily by no means always be improved upon, has become experimented [16]. The optimal position and also optimum capacity of any particular variety of FACTS in the power technique is an impede regarding combinatorial modification [18] [19]. Various kinds of optimization protocol are accustomed to attempt away this sort of issue, for example genetic algorithms, reproduced annealing, tabu search and etc. [17] [20].

This paper proposed a hybrid method for improving the dynamic stability of the power system using UPFC is proposed. The novelty of the proposed method is combined performance of the Bat-inspired algorithm and Firefly Algorithm (FA), which provides improved searching ability, automatic subdivision and random reduction. Here, the bat-inspired algorithm optimizes the maximum power loss bus while the generator fault occurs, which inturn affects the power flow constraints like voltage, power loss, real and reactive power. For improving the dynamic performance, the optimum capacity of UPFC has been determined with minimum cost by using the FA algorithm. The attained capacity UPFC has been located in the affected location and analyzes the power flow of the system. The objective function mainly helps to improve the bus voltage profile and the power loss reduction. The rest of the paper is organized as follows: 3. Past to that particular, this current exploration works tend to be offered with section 2. The effects along with the discussion tend to be offered with section 4. Within section 5 the paper is usually concludes.

2. Recent Research Work: A Brief Review

Number of similar performs are available in literary works, which dependent on improving the power transfer ability to electrical power process. Some of them are usually assessed here. H.I. Shaheen et al. have been looked at the actual skills from the optimal location of UPFC pertaining to enhancing the basic safety of electrical power methods under single series contingencies [21]. Fortitudes from the severest likelihood predicaments were performed while using emergency alternative along with ranking process. On the list of fresh computational thinking ability methods, specifically: DE have been efficiently utilized to the condition under distress. Maximization of electrical power process stability had been considered as the actual optimization tip. The style of DE had been compared with in which of GA and PSO. Besides, these were performed a two case scientific studies having an IEEE 14-bus process and the IEEE 30-bus system.

Husam I. Shaheen et al. has proposed method according to differential evolution technique under single line contingencies, to identify the optimal location and parameter establishing connected with UPFC intended for improving the electric power system safety measures [22]. Initially, to help discover probably the most accurate line outage contingencies taking into consideration line overloads and bus voltage limit violations as a presentation index, they put into practice an unexpected emergency research and ranking process. Next, they employ differential evolution technique to identify the optimal location and parameter setting of UPFC within the determined contingency cases. They will perform simulations while on an IEEE 14-bus and a good IEEE 30-bus power systems. These accomplished effects reveals the installation of UPFC within the area optimized by means of DE can significantly enhanced this protection connected with electric power system through the elimination or perhaps reducing this overloaded lines and the bus voltage limit violations.

Seyed Abbas Taher et al. have got introduced this demands connected with hybrid immune algorithm to have the optimum location of UPFCs for attaining minimum total active and reactive power production cost of generators and reducing the installation cost of UPFCs [23]. The UPFC offers control of voltage magnitude, voltage phase angle and impedance. Consequently, it had been utilized successfully in this paper to raise power transfer capability of this introduced power transmission lines, and minimize operational and investment charges.

UPFC moreover gives a system that might help traditional congestion mitigation approaches and perhaps may possibly flip away generators to run in beyond advantage order, and thus may restrict load shedding or perhaps constraint that was generally necessary to maintain process security. They executed simulations upon IEEE 14-bus and 30-bus test system.

T. Nireekshana et al. [24] have tested the usage of FACTs devices, including SVC along with TCSC, to look at whole improved factors about the power transfer transactions during normal and unexpected emergency situations. Making use of Continuation Power Flow (CPF) strategy, ATC has been worked out considering each thermal limits and voltage profile. Real-code Genetic Algorithm (RGA) has been used as an optimization tool for you to detect the location along with controlling parameters involving SVC and TCSC. The proposed methodology has been screened on IEEE 14-bus system plus on IEEE 24-bus reliability test system intended for normal and different emergency cases.

A.R. Phadke et al. have suggested an approach regarding engagement and sizing of shunt FACTS controller by means of Fuzzy logic and Real Coded Genetic Algorithm [25]. A fuzzy appearance index according to distance to impede node bifurcation, voltage profile and capacity of shunt FACTS controller is proposed. Your suggested strategy may be used along with ideal sizing on the shunt FACTS equipment in order to discover essentially the most competent position. The proposed strategy has been used with IEEE 14-bus along with IEEE 57-bus test systems.

Chuan Wang et al. [26] have planned a new hybrid topology scale-free Gaussian-dynamic particle swarm (HTSFGDPS) optimization algorithm for real power loss minimization problem of power system. The swarm population was broken down directly into a couple of elements: hybrid topology population and scale-free topology population. The fresh hybrid topology was blended with totally attached topology in addition to ring topology. After that, this permits the particles to possess more robust pursuit potential in addition to quick convergence rate concurrently. Within the scale-free part, the particular topology will likely be progressively made of development process and the optimization process progress synchronously. Because of this, the particular topology displays disassortative mixing property, which may enhance the swarm population diversity. Many people focus on a new combination of swarm intelligence optimization theory and complex network theory, as well as its application to electric power system.

M.R.Banaei et al. [27] have proposed a dynamic model of power system installed which has a fresh UPFC of which contain a pair of shunt converters as well as a series capacitor. On this settings, a series capacitor can be used among a pair of shunt converters to suitable desired series voltage. Therefore, it was achievable to control the active and reactive power flow. Furthermore, linearized Phillips–Heffron model can be obtained as well as a second controller with the modeling regarding suggested UPFC to damp low frequency oscillations having considering four alternative damping controllers was suggested. The issue regarding robustly fresh UPFC centered damping controller was formulated just as optimization problem according to the time domain-based objective function, which were sorted making use of particle swarm optimization (PSO) and Imperialist Competitive Algorithm (ICA) techniques.

The heavily loaded connections, keep the particular bus voltages at preferred quantities, as well as improve the stability of the power network tend to be maximized uncontrolled exchanges throughout electric power techniques. Because of this, electric power techniques should be monitored in series throughout the particular network effectively. FACTS devices will depends on the progress of the semiconductor technological innovation introduced optimistic most current potential prospects regarding controlling the power flow and expanding the loadability from the obtainable electric power transmission process. On the list of FACTS devices, the particular UPFC is almost all ensuring FACTS devices regarding load flow control viewing as it could often along control the energetic as well as reactive electric power flow with the particular lines beyond just the nodal voltages. Depending on the particular qualities with the UPFC, preparation of implementations, it has got some realistic issue pertaining to seeking the optimal location. With practically, the optimal position of UPFC seems not by simply randomly, plus the complementing methodical exploration seriously isn't generally satisfactory. Several analyses include attempts in order to resolve the optimal position of UPFCs with respect to different purposes along with approaches. Pertaining to figuring out the optimal position, the particular operating condition of UPFC has to be pre-assigned. A number of the optimization algorithms are usually unveiled to look for the position along with dimensions of UPFC like genetic algorithm, particle swarm optimization, differential evaluation and so forth. This is not applying to obtain the ability along with position in same moment in order that the hybrid approach should be applied. The particular proposed technique is usually explained in brief in the upcoming section.

3. Power System Model with UPFC

The UPFC (unified power flow controller) is a FACTS device able to control simultaneously active power flows, reactive power flows, and voltage magnitude at the UPFC terminals. Here, the UPFC may be seen to consist of two voltage source converters, i.e., converter 1 and converter 2, connected back to back through a common DC link provided by a DC storage capacitor. The converter 1 is a shunt connected voltage source converter to the network, which is used to generate or absorb controllable reactive power and shunt reactive compensation for the line [28]. The converter 2 performs the main function of UPFC by bringing in an AC voltage with magnitude that can be controlled and the phase angle is in series with the transmission line through a series transformer [29, 30]. The necessary reactive power is supplied or absorbed locally by converter 2 and active power is replaced as a consequence of the series injection voltage [41, 42]. The UPFC structure basic arrangement between i and j bus is described in the following figure 1.

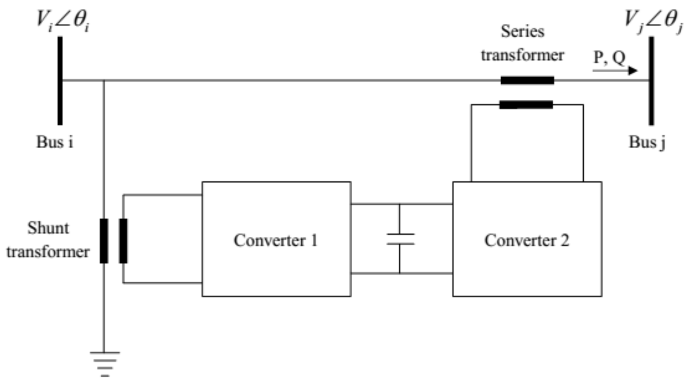

Figure 1. UPFC structure basic arrangement

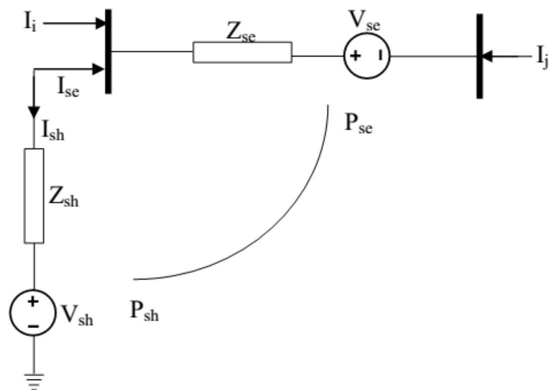

Figure 2. UPFC equivalent circuit

The UPFC equivalent circuit model is described in the following figure 2. The UPFC is located between i and j bus. The real and reactive power at the bus i and j are calculated by using the load flow solution. The symmetric characteristics of admittance matrix will not be damaged [31] and that is the significance of the power injection representation. The reactive and real power injection at every bus is illustrated [32] in the following. The UPFC model power flow equations are described in the following.

Power flows from i to j:

$$\begin{aligned} P_{ij}(t) = &\left(V_i^{2(t)} + V_{kl}^{2(t)}\right)G_{ij}^{(t)} + 2V_i^{(t)}V_{kl}^{(t)}G_{ij}^{(t)}\cos(\alpha_{kl} - \phi_j) \\ &- V_j^{(t)}V_{kl}^{(t)}\left[G_{ij}^{(t)}\cos(\alpha_{kl} - \phi_j) + b_{ij}^{(t)}(\sin\alpha_{kl} - \phi_j)\right] \\ &- V_i^{(t)}V_j^{(t)}\left(G_{ij}^{(t)}\cos\phi_{ij} + b_{ij}^{(t)}\sin\phi_{ij}\right) \end{aligned} \tag{1}$$

$$\begin{aligned} Q_{ij}(t) = &-V_i^{(t)}I^{(t)} - V_i^{2(t)}(b_{ij}^{(t)} + B/2) \\ &- V_i^{(t)}V_{kl}^{(t)}\left[G_{ij}^{(t)}\sin(\alpha_{kl} - \phi_i) + b_{ij}^{(t)}(\cos\alpha_{kl} - \phi_i)\right] \\ &- V_i^{(t)}V_j^{(t)}\left(G_{ij}^{(t)}\sin\phi_{ij} - b_{ij}^{(t)}\cos\phi_{ij}\right) \end{aligned} \tag{2}$$

Where, $G_{ij} + jb_{ij} = \dfrac{1}{R_{ij} + jX_{ij}}$; V_i and V_j are the voltage of the buses i and j respectively and V_{kl} is the voltage of the compensating device, similarly the real and reactive power flow from the bus j to i is given by the following equation (3) and (4).

Power flows from j to i:

$$\begin{aligned} P_{ji}(t) = &V_j^{2(t)}G_{ij}^{(t)} - [V_j^{(t)}V_{kl}^{(t)}G_{ij}^{(t)}\cos(\alpha_{kl} - \phi_j) - b_{ij}^{(t)}G^{(t)}\sin(\alpha_{kl} - \phi_j)] \\ &- V_i^{(t)}V_j^{(t)}\left(G_{ij}^{(t)}\cos\phi_{ij} - b_{ij}^{(t)}\sin\phi_{ij}\right) \end{aligned} \tag{3}$$

$$\begin{aligned} Q_{ji}(t) = &-V_j^{2(t)}(b_{ij}^{(t)} + B/2) - V_j^{(t)}V_{kl}^{(t)} \\ &\left[G_{ij}^{(t)}\sin(\alpha_{kl} - \phi_j) - b_{ij}^{(t)}(\cos\alpha_{kl} - \phi_j)\right] \\ &+ V_i^{(t)}V_j^{(t)}\left(G_{ij}^{(t)}\sin\phi_{ij} - b_{ij}^{(t)}\cos\phi_{ij}\right) \end{aligned} \tag{4}$$

The above mentioned power flow equations are used to find out the capacity of UPFC. The capacity of UPFC can be decided depending on the dynamic stability constraints. Normally the system could be in stable condition and whenever the generator fault occurs, the system observes constraints. The situation is solved by the optimum location and capacity of the UPFC, which should satisfy the dynamic stability constraints. The required objective of the dynamic stability and the constraints are described in the following section 3.1.

A. Dynamic stability constraints

The power system dynamic stability has been achieved by maintaining the dynamic stability constraints or the control variables at secure limits. The objective function is mainly used to optimize the most affected location and optimum capacity, i.e., maximum power loss and minimum voltage deviation. Here, the objective function is subject to the control variables such as power balance condition, power loss, voltage stability, UPFC cost, real and reactive power flow.

(i). Power balance equation

The power system generated power must satisfy the demand of the system as well as the power loss. The generators presented in the system may get outage, which means the power loss of the buses is increased, which violates the power balance condition. The required power balance condition is explained in the equation (5).

$$\sum_{i=1}^{N_G} P_G^i = P_D + \sum_{j=1}^{N_G} (P_L^j + jQ_L^j) \tag{5}$$

Where, Where, P_G^i is the power generated in the i^{th} bus, P_D is the demand, P_L^j and Q_L^j are the real and reactive power loss of the j^{th} bus. The generators generation limits and demand of the system are described in the following equation (6) and (7).

$$P_G^{i(\min)} \le P_G^i \le P_G^{i(\max)} \tag{6}$$

$$P_D^{(\min)} \le P_D \le P_D^{(\max)}$$

Where, $P_G^{i(\min)}$ and $P_G^{i(\max)}$ are the minimum maximum range of the generators generation limits, $P_D^{(\min)}$ and $P_D^{(\max)}$ are the minimum maximum range of the load demand limits. The bus power loss constraint is discussed in the following section.

(ii). Power loss

The real and reactive power loss can be formulated by the following equation (8) and (9).

$$P_L^j = |V_i||V_j||Y_{ij}|\sum_{n=1}^{N} \cos(\alpha_{ij} - \delta_i - \delta_j) \tag{8}$$

$$Q_L^j = |V_i||V_j||Y_{ij}|\sum_{n=1}^{N} \sin(\alpha_{ij} - \delta_i - \delta_j) \tag{9}$$

Where, V_i and V_j are the voltage of the buses i and j, Y_{ij} is the bus admittance matrix, α_{ij} is the angle between the buses i and j, δ_i and δ_j are the load angle of i and j. Similarly the inequality constraints are described in the following.

(iii). Real and reactive power flow

The real and reactive power i^{th} bus can be described by the following equations (10) and (11).

$$P_i = |V_i||V_j|\sum_{n=1}^{N_B} \left(G_{ij} \cos\delta_{ij} + B_{ij} \sin\delta_{ij}\right) \tag{10}$$

$$Q_i = |V_i||V_j|\sum_{n=1}^{N_B} \left(G_{ij} \sin\delta_{ij} - B_{ij} \cos\delta_{ij}\right) \tag{11}$$

Where, V_i and V_j are the voltage of i and j buses respectively, N_B is the total number of buses, δ_{ij} and δ_{ij} are the angle between i and j buses respectively, G_{ij} and B_{ij} are the conductance and susceptance values respectively.

(iv). Voltage stability

The voltage stability of the each bus is the main factor of the dynamic stability, which can be described by the following equations (12).

$$\Delta V_i = \frac{1}{\sqrt{l}} \sqrt{\sum_{i=1}^{l} \left(V_i^{\,k}\right)^2} \tag{12}$$

Where,

$$V_i^{\,k} = V_{slack} - \sum_{i=1}^{n} Z_i \left(\frac{P_i - jQ_i}{V_i} \right)$$

With, V_{slack} is the slack bus voltage, ΔV_i is the voltage stability index of the bus i, V_i is voltage of the bus, where $i = 1,2,3\ldots n$, Z_i is the impedance of the i^{th} bus, P_i and Q_i are the real and reactive power of bus i and j is the number of nodes. The UPFC cost constraint is described in the following.

(v). UPFC cost

The UPFC cost can be determined by the following equation (13).

$$Cost(UPFC) = 0.0003S^2 - 0.269S + 188.22 \ (\$ / KVAR) \tag{13}$$

Where, S is the operating range of the facts devices in MVAR. The proposed hybrid method is utilized into two categories such as Bat algorithm for identifying the optimum location of the UPFC and FA algorithm for finding the optimum capacity of the UPFC at reduced cost. The bat algorithm based optimum location of the UPFC determination is briefly described in the following section 3.2.

B. Bat algorithm based UPFC location determination

This section describes about the determination of the UPFC location using bat inspired algorithm. The bat inspired algorithm is the optimization algorithm, which works based on the echolocation behavior of bats [33, 34]. Here, the Newton Raphson (N-R) method is used for the load flow analysis of the IEEE standard bench mark system. Then the generator fault is introduced in the system, during this time the bat-inspired algorithm is used to find the most affected bus, i.e., maximum power loss bus, which is the optimum location. The maximum power loss bus is the most suitable bus to locate the UPFC. At the beginning, the input micro-bats like voltage at each bus and the power loss are initialized, which is given in the following equation (14).

$$B_i = [(V_1, P_{L1})^1, (V_2, P_{L2})^2, (V_3, P_{L3})^3 \ldots (V_n, P_{Ln})^n] \tag{14}$$

Where, B_i is the micro-bats. The input bus voltage is randomly generated with the required n dimensions search space. Here, each micro-bat have the velocity vector (v_i) and position vector (x_i) and echolocation parameters like frequency (f_i), pulse rate (r_i) and the loudness parameters (l_i), which are given in the following equation (15), (16) and (17).

$$f_{\min} \le f_i \le f_{\max} \tag{15}$$

$$r_{\min} \le r_i \le r_{\max} \tag{16}$$

$$l_{\min} \le l_i \le l_{\max} \tag{17}$$

Here, we assign the frequency range $f_{\min} = 0$ and $f_{\max} = 1$, the pulse rate minimum value is $r_{\min} = 0.5$ and the loudness maximum value is $l_{\max} = 1$. The remaining values are determined by the following equation (18).

$$l_{\min} = \frac{1}{\sqrt{n_{\sec}}} \text{ and } r_{\max} = 1 - \frac{1}{n_d} \le 1 \tag{18}$$

Where, $n_{\sec}$ is the number of sections in the discrete set used for sizing the design variable and $n_{\sec}$ is the number of discrete design variables. Then the objective function is evaluated, using the following equation (19).

$$\Phi = Max\left\{ |V_i||V_j||Y_{ij}| \sum_{n=1}^{N} \cos(\alpha_{ij} - \delta_i - \delta_j) \right\} \tag{19}$$

The current populations of micro-bats are randomly updated based on the frequency and the velocity. The frequency and the velocity calculation are explained in the following equation (20) and (20).

$$f_i^t = f_{\min} + (f_{\max} - f_{\min})u_i \tag{20}$$

Where, the random number of values, which is selected from 0 to 1, then the frequency is applied into the velocity equation, which can be described in the following.

$$v_i^t = round\ [v_i^{t-1} + (X_i^{t-1} - X_\Psi)u_i] \tag{21}$$

Where, v_i^t and v_i^{t-1} are the velocity vectors of the micro-bats at the time steps t and $t-1$, X_i^t and X_i^{t-1} are the position vectors of the micro-bats at time steps t and $t-1$, X_Ψ is the current global best solution. Here after the local search is performed in the randomly selected population that is described in the following equation (22).

$$x_i^t = x_i^{t-1} + \xi_{i,j} l_{avg}^t \tag{22}$$

Where, $\xi_{i,j}$ is a random number between -1 and 1, l_{avg}^t is the average value of loudness at time step t . Then find the fitness of the new micro-bats using equation (19) and improve the echolocation parameters.

$$l_i^{'} = a.l_i \ \ and \ \ r_i^{t+1} = r_{\max}[1 - \exp(\gamma t)] \tag{23}$$

Where, $l_i^{'}$ and l_i are the previous and updated values of the loudness, r^{t+1} is the pulse rate of the micro-bats in time step , a and γ are the adaptation parameters of the loudness and pulse rate. Then the steps to find the optimum location are described in the following section.

Steps to find the optimum location

Step 1: Initialize the micro-bats are randomly generated at N dimension. Here, the bus voltage and line losses are the input micro-bats.
Step 2: Evaluate the objective function for the random number of the micro-bats.
Step 3: The solutions are separated into two groups, the first groups have the minimum best solutions and another group has maximum best solutions.
Step 4: Find the best solution according to the objective function and store the current population.
Step 5: Randomly update the current micro-bats population to update position vector and velocity vector of the micro-bats.
Step 6: Evaluate the objective for the new micro-bats population and select the best solution among the solution.
Step 7: Find the power loss, voltage, real and reactive power flow of the best solution.
Step 8: Check the termination criterion. If it is satisfied terminate or else go to step 9.
Step 9: Generate the new agents to generate new solutions. Go to Step 2.

Once this process is finished, the system is ready to give the optimum location to place the UPFC. That location power flow quantities are required to find the capacity of the UPFC, which is possible by the FA algorithm. The brief explanation about the optimum capacity of UPFC identification is given in the following section 3.3.

C. FA algorithm based UPFC capacity determination

FA is invented by Xin-She Yang for solving multimodal optimization problem, which works based on the flashing behavior of fireflies [36, 37 and 38]. Here, the FA can develop the optimum capacity of the UPFC with minimum cost. The objective of the proposed method is minimizing the difference between the bus voltage and normal voltage, i.e., brighter firefly. The selected voltage is used for the power capacity and cost calculation of the UPFC, which is the optimum capacity of the UPFC. By using the optimum capacity of the UPFC, the dynamic stability of the system can be enhanced. The steps to optimize the UPFC capacity are given *in* the following.

Steps to find the optimum capacity
Step 1: Initialize input population of the fireflies. Here, input is the system data like power flow equation of the UPFC and bus system voltage.
Step 2: Generate the random number fireflies of the input firefly's population, which is defined in the following.

$$F_i = \begin{bmatrix} V_{11} & V_{12} & \dots & V_{1n} \\ V_{21} & V_{22} & \dots & V_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ V_{n1} & V_{n2} & \dots & V_{nn} \end{bmatrix} \tag{24}$$

In every firefly assign the light absorption coefficient γ .
Step 3: Set the iteration count t=1.
Step 4: Evaluate the objective function for each firefly using the following function (25).

$$Fitness = Min\{f_1, f_2\} \tag{25}$$

Where, $f_1 = \sum_{i=1}^{N_B} \left(V_{Normal} - V_i^F\right)$ and $f_2 = Cost(UPFC)$

Step 5: Store the current population and increase the iteration count as t+1, i.e., iteration t = t+1.
Step 6: Apply the ranking process and find the current best solution.
Step 7: Rearranging the firefly location by using the following updating equation [35, 38] (26).

$$x_i^{t+1} = x_i^t + \beta_o e^{-\gamma v_{ij}^2} (x_i^t - x_j^t) + \alpha \sigma_i^t \tag{26}$$

Where, β_o is the attractiveness at $v = 0$, the first term is the old firefly position, second term is due to attraction, third term is randomization with vector of random variables σ_i being drawn from a Gaussian distribution, α is the random movement factor and distance between two fireflies i and j at x_i and x_j be a Cartesian distance $v_{ij} = || x_i - x_j ||$. Here, initially α_o and β_o is varied from 0.1 to 1.0 with a step increase of 0.1, γ is varied from 0.01 to 100 with a step increase of 0.01 up to 1 and then 5 up to 100 [38].

Step 8: Determine the new firefly's population objective function and find the best solution. Also calculate the power flow quantities of the best solution.

Step 9: Check the termination criteria, if it is achieved go to step 10 or else go to step 4.

Step 10: Terminate the process.

The attained capacity of the UPFC with minimum cost has been applied to the affected location and analyzes the power flow of the system. The proposed method operation flowchart structure is described in the following figure 3. Then the proposed method is tested under the MATLAB platform by using the standard bench mark system and the effectiveness can be analyzed through the comparison with different techniques. The results are discussed in the following section 4.

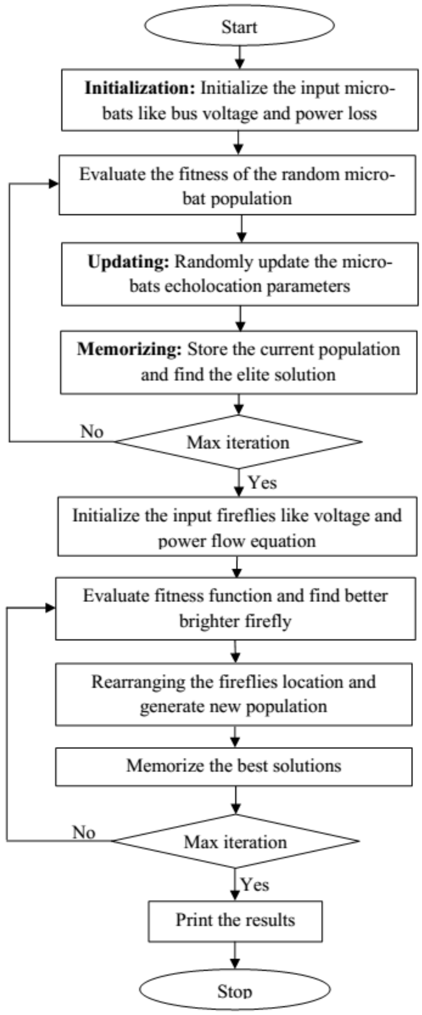

Figure 3. Proposed hybrid method structure

4. Results and Discussion

The proposed mutual method is implemented in MATLAB/Simulink 7.10.0 (R2012a) platform, 4GB RAM and Intel(R) core(TM) i5. Here the IEEE 30 bus system and 14 bus systems are used to validate the proposed method. The numerical results of the proposed method are presented and discussed in this section. The effectiveness of the proposed method is analyzed by comparing with GSA-Bat algorithm [39, 40]. The proposed method is applied in the IEEE 30 bus system and discussed in the following Section 4.1.

A. Testing of IEEE 30 bus system

This section describes about the performance validation of the proposed method. Here, the proposed method is tested in the IEEE 30 bus system and the corresponding numerical results are discussed. Normally IEEE 30 bus system consists of 6 generator bus, 21 load bus and 42 transmission lines, which is described in the following Figure 4. Initially the IEEE 30 bus system normal load flow is analyzed by using the N-R load flow method. Afterwards the generator outages are randomly created (single generator problem and double generator problem) in the generator buses such as 1,2,6,13,22 and 27. Due to the generator faults the bus system loses the dynamic stability, which can be measured by the load flow analysis of the bus system after the generator outage. The power flow after the single generator problem using proposed method is described in Table 1. The power loss and the required capacity UPFC cost using proposed method are mentioned in Table 2.

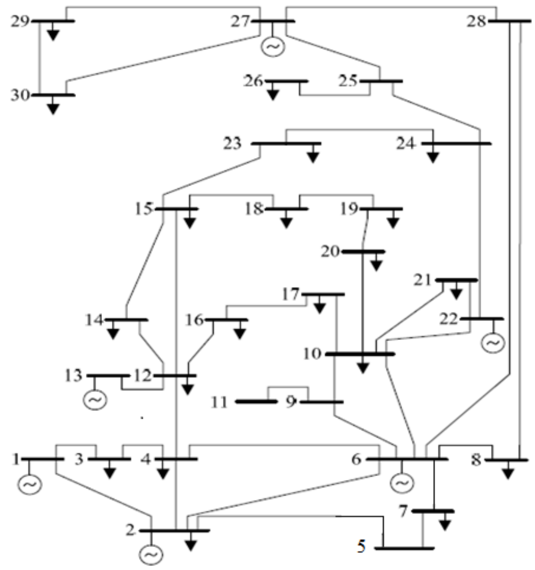

Figure 4. IEEE 30 bus system structure

The IEEE 30 bus system normal bus voltage profile is explained in the following Figure 5. The voltage profile is attained from the normal N-R method. The bus voltage profiles during the second bus generator outage during the fault time and using proposed method are illustrated in Figure 6. From this, we realize that the bus voltage is maintained at the stability limit during the normal power flow condition by means of the N-R method. When the generator gets problem, the bus voltage profile faces the instability. Then the voltage instability is reduced by optimizing the location and the capacity of the UPFC is enhanced using the proposed method. At the 13th bus generator outage, the bus voltage profile using the proposed method is illustrated in Figure 7. These conditions also show that the proposed method effectively attempts to keep up the voltage profile at the stability limit. At the identical generator outage environments, the total power loss of the IEEE bench mark system is measured. Similarly other generator outages are made in the bus system the corresponding results are described in the following figures 8, 9 and 10 respectively. The power loss measurement at single generator problem is described in Figure 11. It shows the superb performance of the proposed method, as the power loss has been considerably reduced compared to the normal time and the fault condition. Then we introduce the double generator problem against the IEEE 30 bus system, and at this time the two generators problem occurs at different time intervals, which may affect the power flow of the bus system. The double generator problem using proposed method is described in Table 3. The double generator problem power loss and the required capacity UPFC cost using proposed method are illustrated in Table 4.

Table 1. Power flow analysis at single generator problem using the proposed method

Generator bus no.	Best location		Power flow					
			Normal		Generator outage		Proposed method	
	From bus	To bus	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
2	10	2	4.0	6.617	4.0	7.581	4.0	7.034
6	29	3	3.7	0.608	3.6	-	4.2	1.712
13	2	4	27.	3.121	34.	2.636	14.	9.845
22	2	5	72.	2.569	74.	2.364	71.	5.375
27	10	2	7.6	3.278	7.4	3.384	7.8	2.315

Table 2. Power loss and UPFC cost at single generator problem using the proposed method

Generator bus no.	Best location		Power loss in MW			UPFC cost ($/KVAR)
	From bus	To bus	Normal	Generator outage	Proposed method	
2	10	22	10.809	12.768	7.3961	187.3277
6	29	30		12.552	6.9820	184.6500
13	2	4		12.795	7.4243	187.0282
22	2	5		11.883	7.1007	185.2987
27	10	20		11.903	7.1671	185.5197

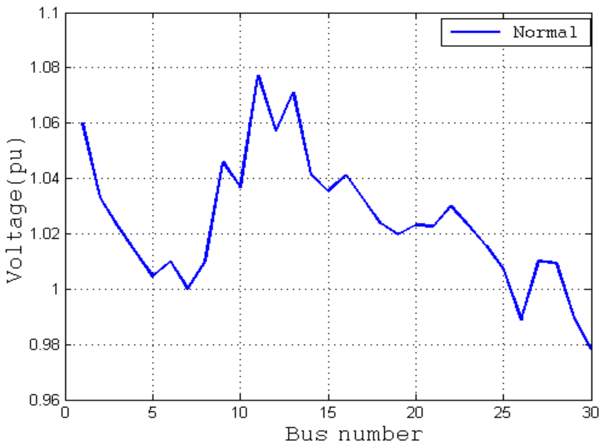

Figure 5. Normal bus voltage profile

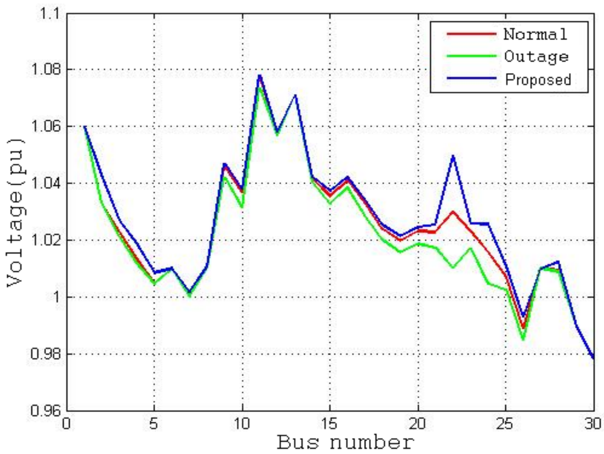

Figure 6. Voltage profile under second bus generator outage

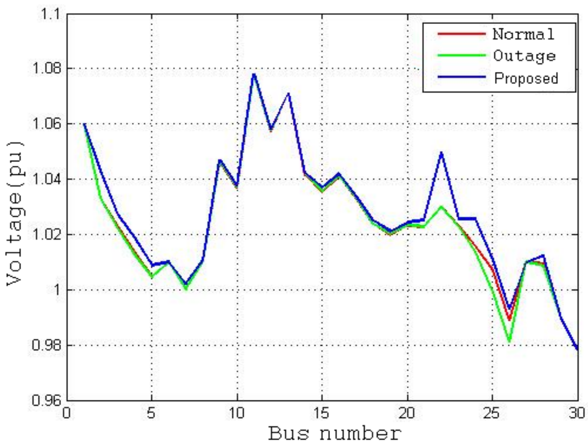

Figure 7. Voltage profile under 6th bus generator outage

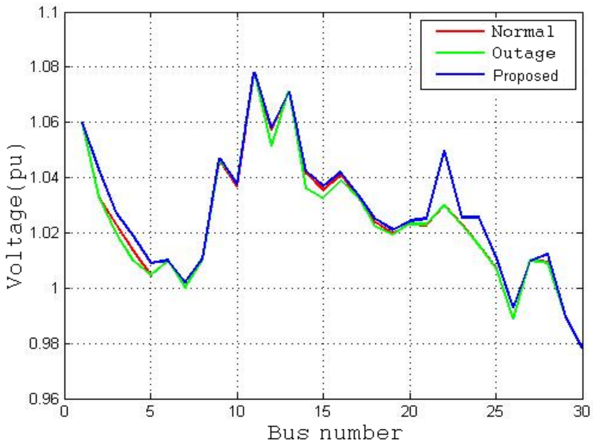

Figure 8. Voltage profile under 13th bus generator outage

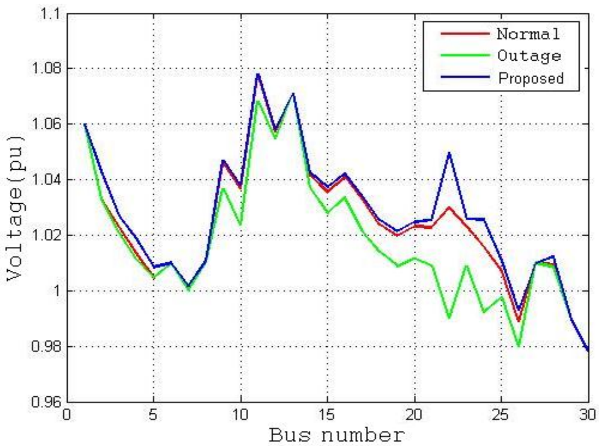

Figure 9. Voltage profile under 22nd bus generator outage

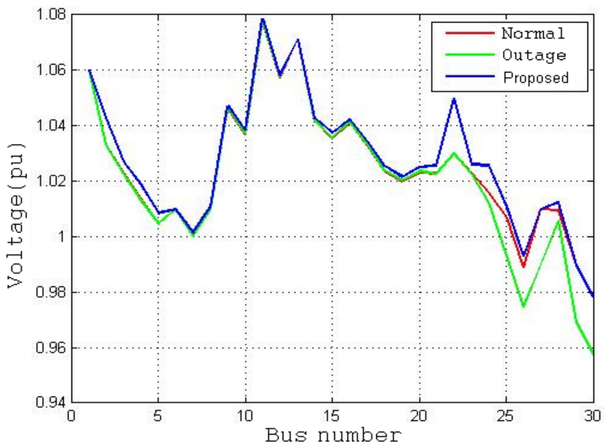

Figure 10. Voltage profile under 27th bus generator outage

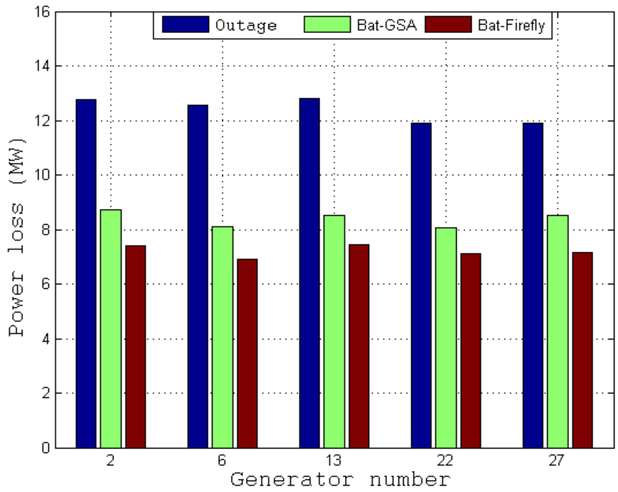

Figure 11. Power loss comparison at single generator outage

Table 3. Power flow analysis at double generator problem using the proposed method

Generator bus no.	Best location		Power flow					
	From bus	To bus	Normal		Generator outage		Proposed method	
			P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
2 and 6	12	15	19.675	7.796	20.191	7.630	18.151	7.981
2 and 13	5	7	23.744	13.825	27.763	14.248	24.995	19.543
6 and 13	5	7	23.744	13.825	18.202	11.525	25.418	20.134
22 and 27	3	4	55.924	5.947	65.165	2.907	56.349	3.396
13 and 27	2	5	72.803	2.549	77.585	2.087	65.037	6.164

Table 4. Power loss and UPFC cost at double generator problem using the proposed method

Generator bus no.	Best location		Power loss in MW			UPFC cost ($/KVAR)
	From bus	To bus	Normal	Generator outage	With UPFC	
2 and 6	10	22	10.809	14.731	7.5595	185.8139
2 and 13	5	7		15.017	7.7399	186.8333
6 and 13	15	23		14.833	7.3471	176.8095
22 and 27	12	15		13.051	7.0381	182.6566
13 and 27	2	5		14.005	7.2911	184.5612

The voltage profile variation according to the different types of double generators outage condition using proposed method is explained in the following Figures 12, 13, 14, 15 and 16. Here, the voltage profile of the proposed method is compared with the fault condition bus voltage profile. When the generator fault occurs in the bus system, the normal bus voltage profile exceeds the stability limit. Depending on the fault range the proposed method identifies the UPFC location and capacity with reduced cost, which is used to resolve the voltage instability problem. The power loss at double generator fault condition using proposed method is explained in the following Figure 17. Here, the normal power loss of the IEEE 30 bus system is 10.809 MW. The normal power loss may increase to 14.005 MW, while the double generators outage problem occurs. The increment of power loss is reduced by locating the optimum capacity UPFC with reduced cost using the proposed method, i.e.7.0381 MW with 176.8096 $/KVAR. Then the proposed method effectiveness is analyzed by comparing the proposed method numerical results with the other hybrid technique GSA-Bat algorithm. The IEEE 30 bus system power loss comparison with different techniques is described in Table 5.

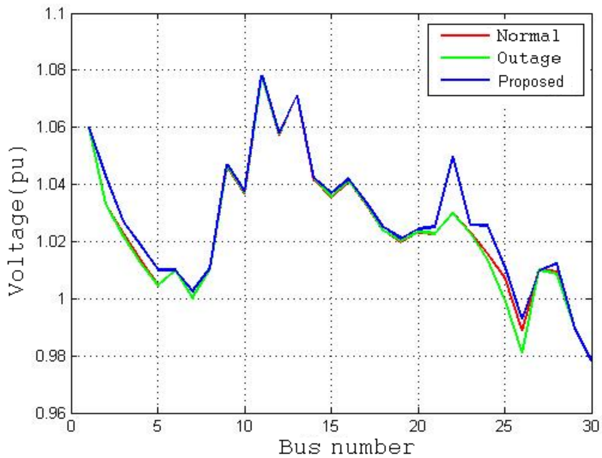

Figure 12. Voltage profile during generator outage at buses 2 and 6

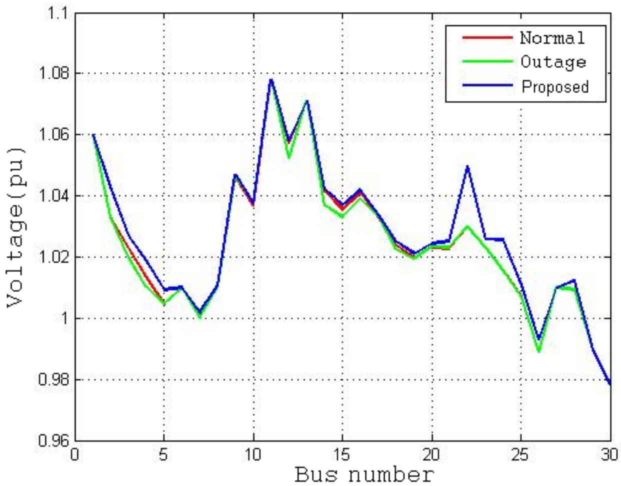

Figure 13. Voltage profile during generator outage at buses 2 and 13

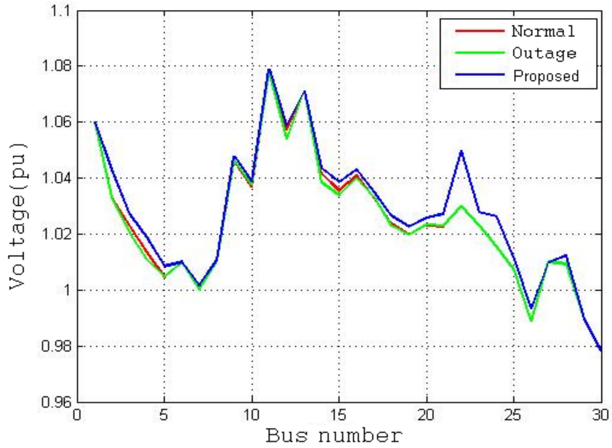

Figure 14. Voltage profile during generator outage at buses 6 and 13

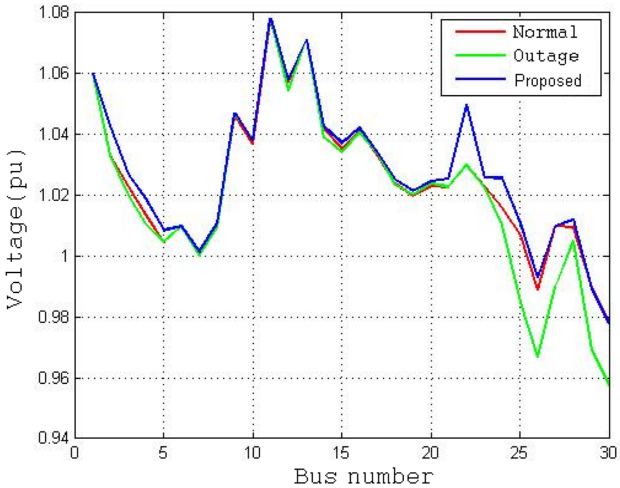

Figure 15. Voltage profile during generator outage at buses 13 and 27

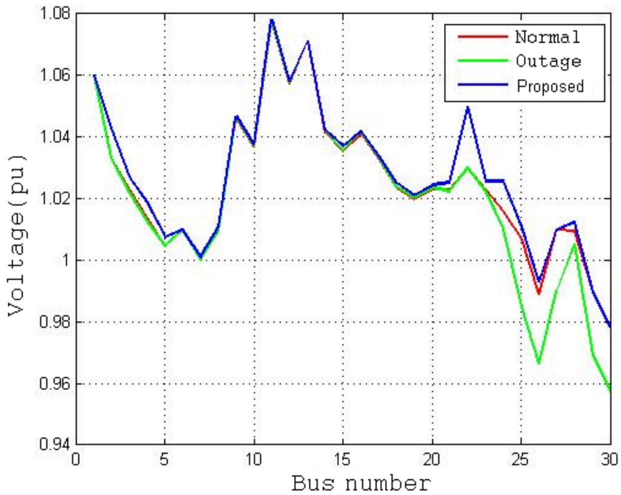

Figure 16. Voltage profile during generator outage at buses 22 and 27

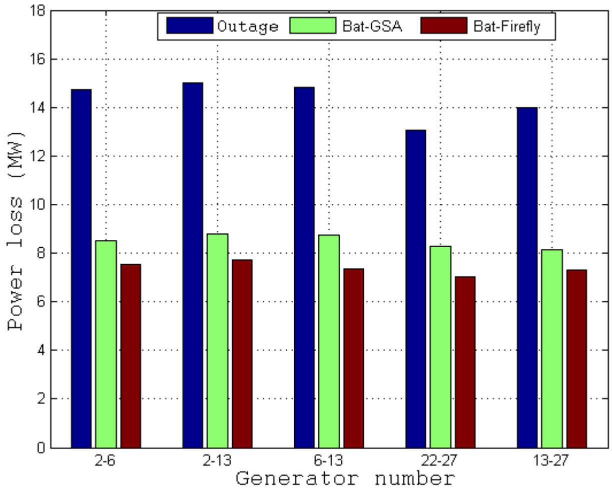

Figure 17. Power loss comparison at double generator outage

Table 5. Power loss comparison at single generator problem using different techniques

Fault Generator bus no.	Best location		Power loss in MW					
	From bus	To bus	Normal	Generator outage	Firefly	ABC-GSA	GSA-Bat	Proposed method
2	12	15	10.809	14.005	9.884	9.498	8.718	7.3961

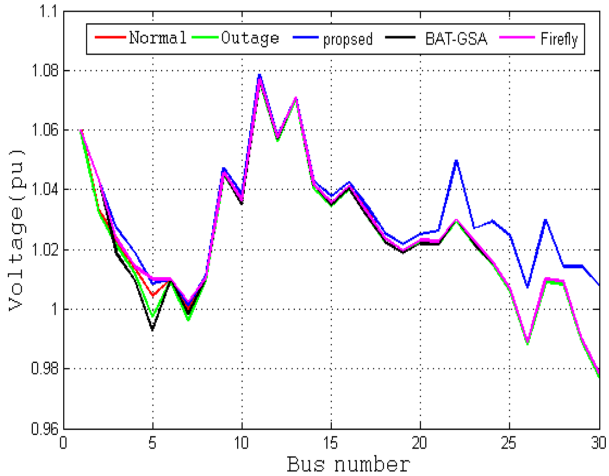

Figure 18. Voltage profile comparison at single generator problem

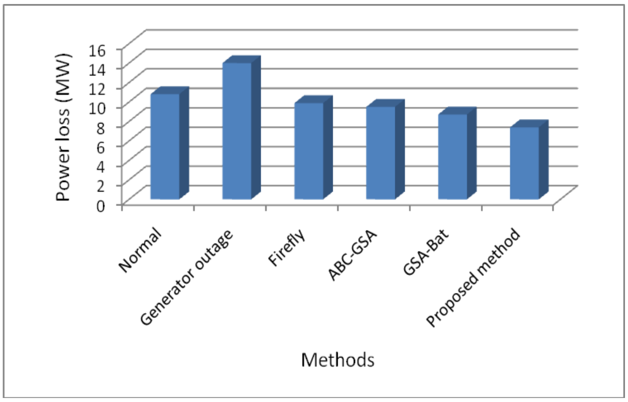

Figure 19. Power loss comparison at single generator problem

The voltage profile of the IEEE 30 bus system at single generator problem employing various methods is illustrated in Figure 18. And the power loss comparison employing various methods is pictured in Figure 19. From this we come to know that the innovative technique efficiently chooses the optimum location and capacity of the UPFC in relation to the other optimization methods. The innovative technique dynamically preserves the dynamic stability of the IEEE 30 bus test system, thus keeping the voltage profile at the stability limit and decreasing the power loss (7.0381 MW). The efficiency of the novel method is also authenticated by means of the IEEE 14 bus system, which is concisely explained in the ensuing Section 4.2.

B. Testing of IEEE 14 bus system

This section spells out the data on the innovative technique which is executed in the IEEE 14 bus system, which comprises 2 generator buses, with one generator in slack bus and the other in the second bus. The IEEE 14 bus test system structure is illustrated in the following Figure 20. The load flow solution at regular circumstances is estimated by means of the N-R load flow analysis, which recognizes the entire system parameters such as bus voltage, power loss and the like. Here, we are introduced to the generator fault at the second bus. At this time the power flow of the system faces difficulties like voltage instability and maximum power loss, which are solved by recognizing the problem location and setting up suitable capacity of the UPFC. The power flow comparisons at single generator problem using different techniques are described in Table 6. The single generator problem power loss comparison is illustrated in Table 7.

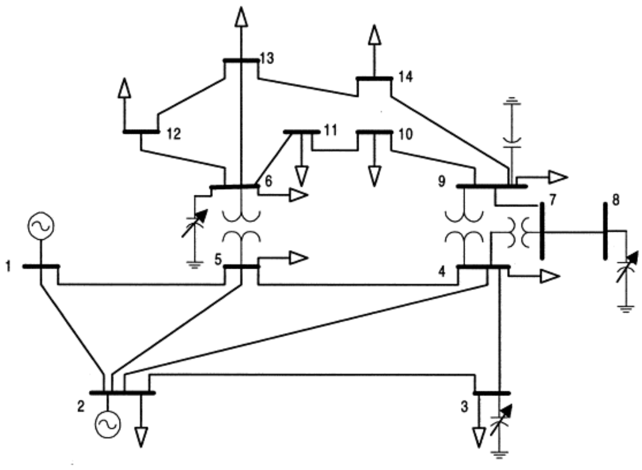

Figure 20. IEEE 14 bus system structure

Table 6. Power flow comparison using different techniques

Technique	Fault Generator bus no.	Best location		Power flow during normal condition		Power flow during fault condition		Power flow after fixing the UPFC	
		From	To bus	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
GSA-Bat	2	4	5	59.585	11.574	62.894	14.208	54.284	11.131
Proposed	2	6	11	8.287	8.898	8.232	7.928	6.265	7.856

Table 7. Power loss comparison using different techniques

Fault Generator bus no.	Best location		Power loss in MW					
	From bus	To bus	Normal	Fault	Firefly	ABC-GSA	GSA-Bat	Proposed method
2	4	5	13.592	15.428	12.924	11.175	10.275	9.623

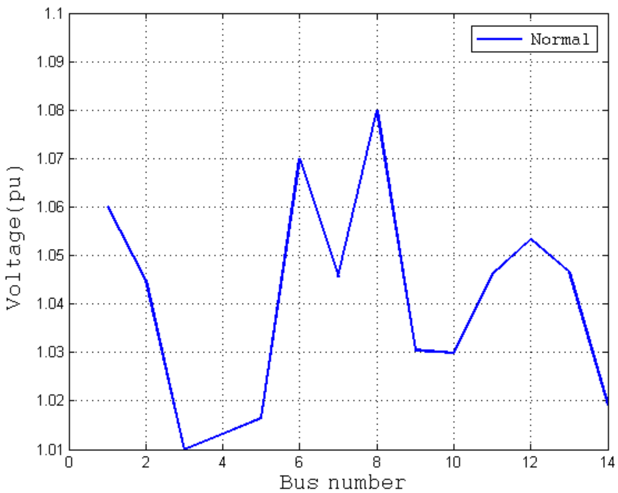

Figure 21. Normal bus voltage profile

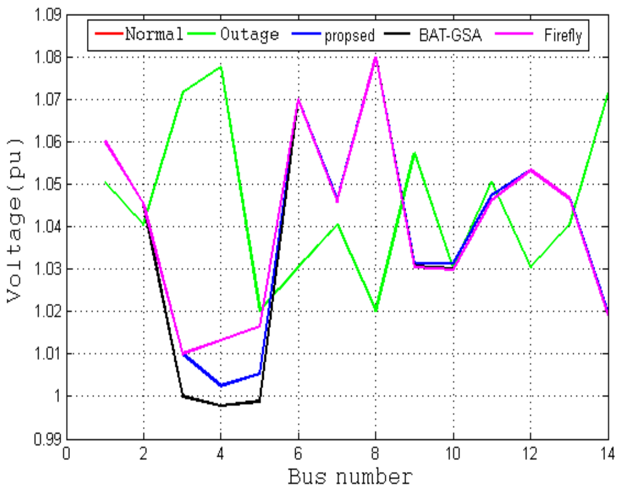

Figure 22. Voltage profile comparison at single generator problem

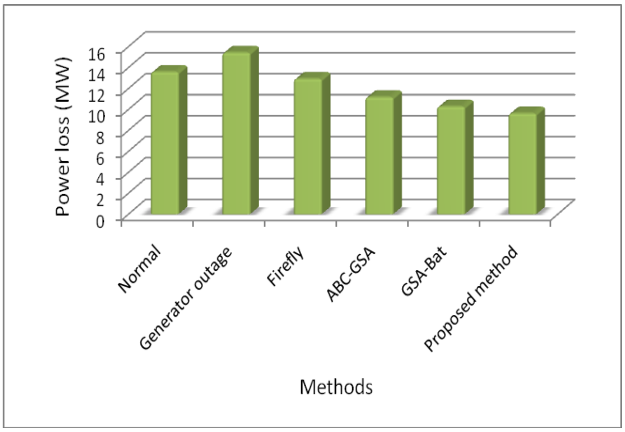

Figure 23. Power loss comparison at single generator outage problem

Table 8. Statistical evaluation of dynamic stability enhancement after 100 runs

System	Mean		Median		Std.deviation		Minimum		Maximum	
	Obj1	Obj2	Obj1	Obj2	Obj1	Obj2	Obj1	Obj2	Obj1	Obj2
IEEE 30	10.9881	1.1123	10.8639	1.1105	2.3092	0.0683	7.0569	0.9954	14.9323	1.2207
IEEE 14	12.6058	1.0809	12.6132	1.0699	1.6157	0.0598	9.6306	0.9862	15.3621 15.3561	1.1811

The IEEE 14 bus system normal voltage profile is described in the figure 21. The voltage profile of the IEEE 14 bus system employing diverse methods at single generator problem is picture in Figure 22. It is crystal clear that the novel technique considerably enhances the voltage profile from the divergence. The power loss by means of the innovative technique is analyzed and contrasted with the hybrid GSA-Bat algorithm as illustrated in Figure 23. From this it evident that the voltage profile is dynamically preserved at the stability limit by means of the novel technique in comparison to the parallel peer techniques. The power loss of IEEE 14 bus system is efficiently decreased to 9.623 MW by using the anticipated technique, which ushers in a superb performance in relation to the GSA and Bat algorithm. The statistical analysis of the proposed method after 100 iteration for objective 1 and objective 2 is shown in the table 8. The cheering outcomes emerging out of the comparison and contrast of the systems underscore the overall supremacy of our magnificent technique which establishes itself as the most efficient technique by consistently preserving the dynamic stability of the power system vis-à-vis its peer techniques.

5. Conclusion

This paper describes about the hybrid technique based improvement on the dynamic stability of the power system. In the proposed technique, the maximum power loss bus is referred as the optimum location of the UPFC, which was obtained by the bat inspired algorithm. By using the optimum location parameters the FA identifies the suitable capacity of the UPFC with minimum cost. The selected capacity of the UPFC is located in the optimum location and the power flow has been analyzed. The advantage of the proposed method is capability and robustness to solve the complex optimization problem. In the results, system bus voltage, power loss, real and reactive power flow were analyzed. Then the proposed method's effectiveness was tested by the comparison analysis with the GSA-Bat algorithm. The comparison results proved that the proposed method is the most effective technique to maintain the dynamic stability of the power system, which is competent over the other techniques.

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